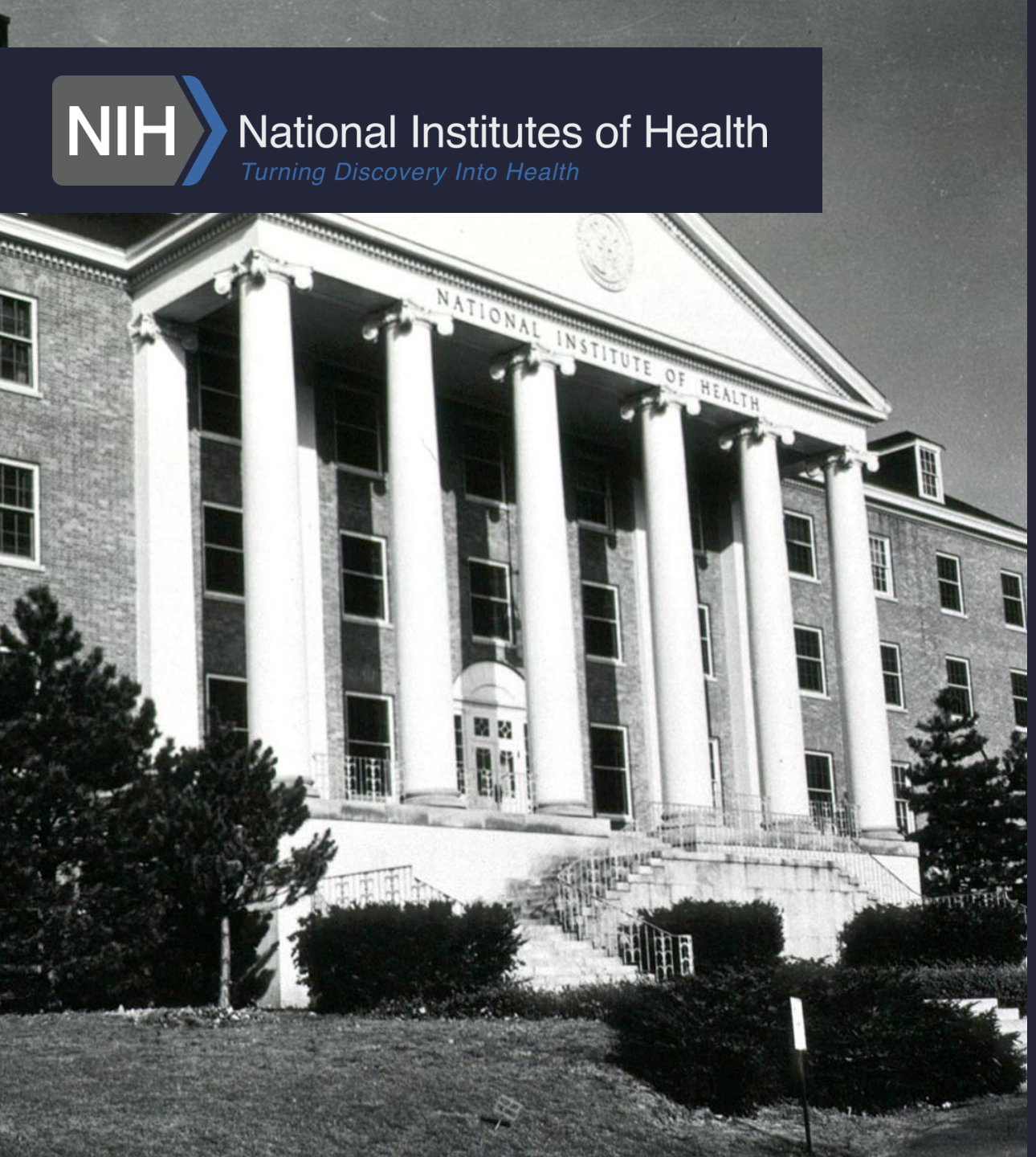


NIH National Institutes of Health
Turning Discovery Into Health

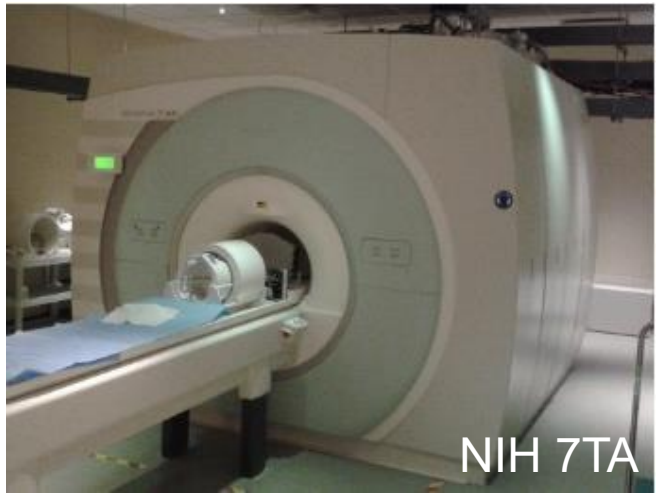
Functional MRI at 7 Tesla

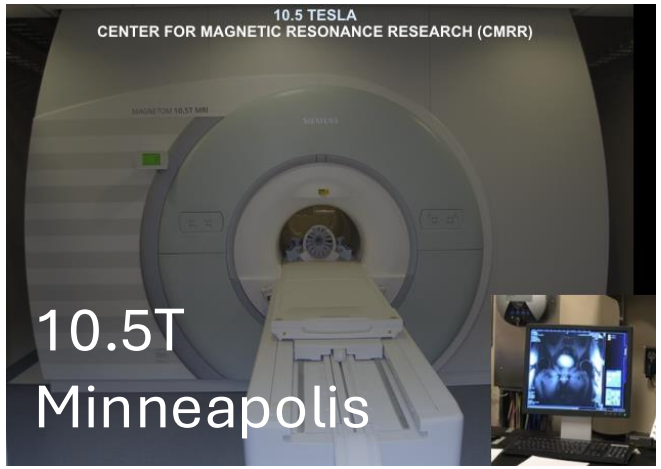
fMRI Summer Course 2026
Thursday, August 13

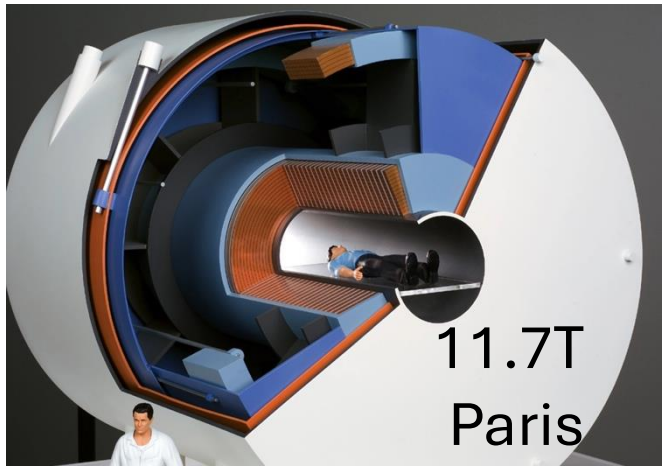
Tyler Morgan
Functional MRI Core Facility

Functional MRI at 7T (or even higher fields!)

- We sometimes require higher resolutions or more signal than traditional fMRI can provide
- Typically, that means using an ultra high-field MRI machine
- These can include 7 Tesla, 9.4T, 10.5T, 11.7T, or even 14T!

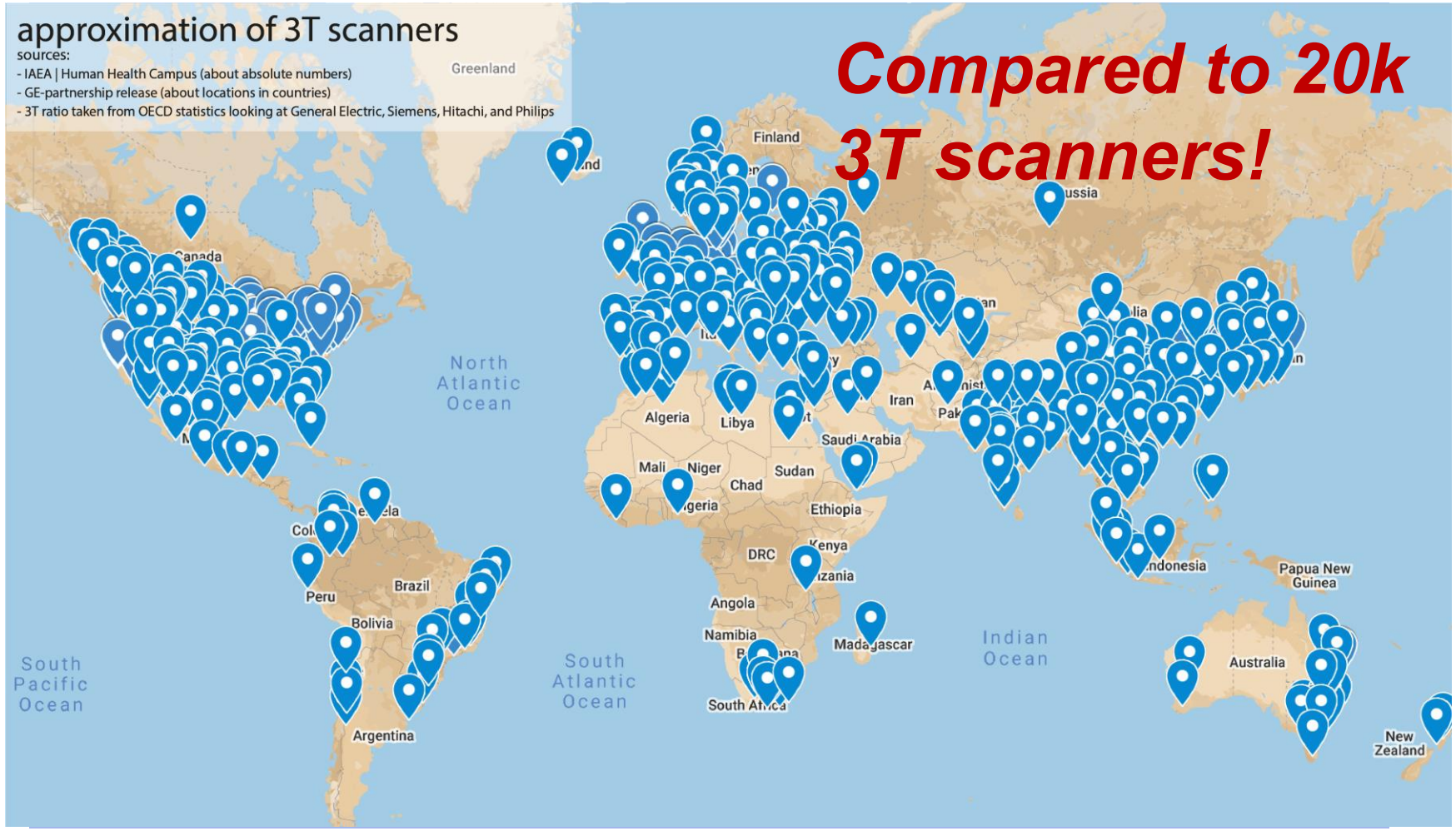






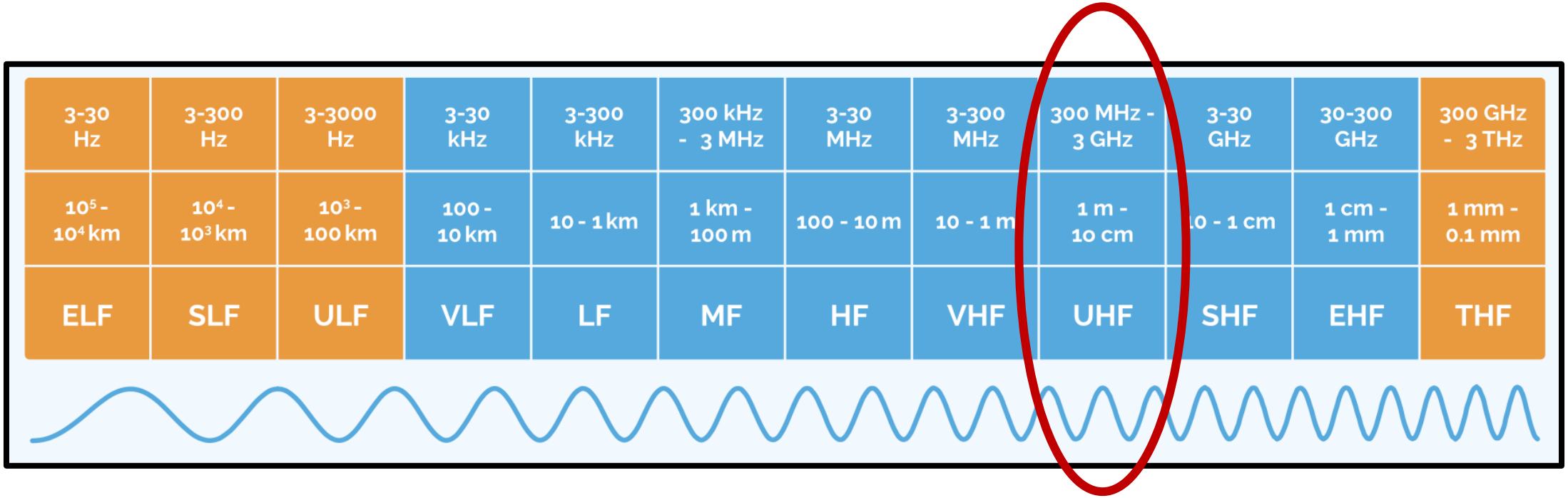
Ultra high-field MRI around the World

- In 2015, there were approximately 40 human UHF MRIs in the world
- Today, there are about 140 of them!
- Nearly 45 of those are in North America
- ***And there are 3 downstairs!***



Layer fMRI Google Map

But why is it called Ultra High-Field MRI?



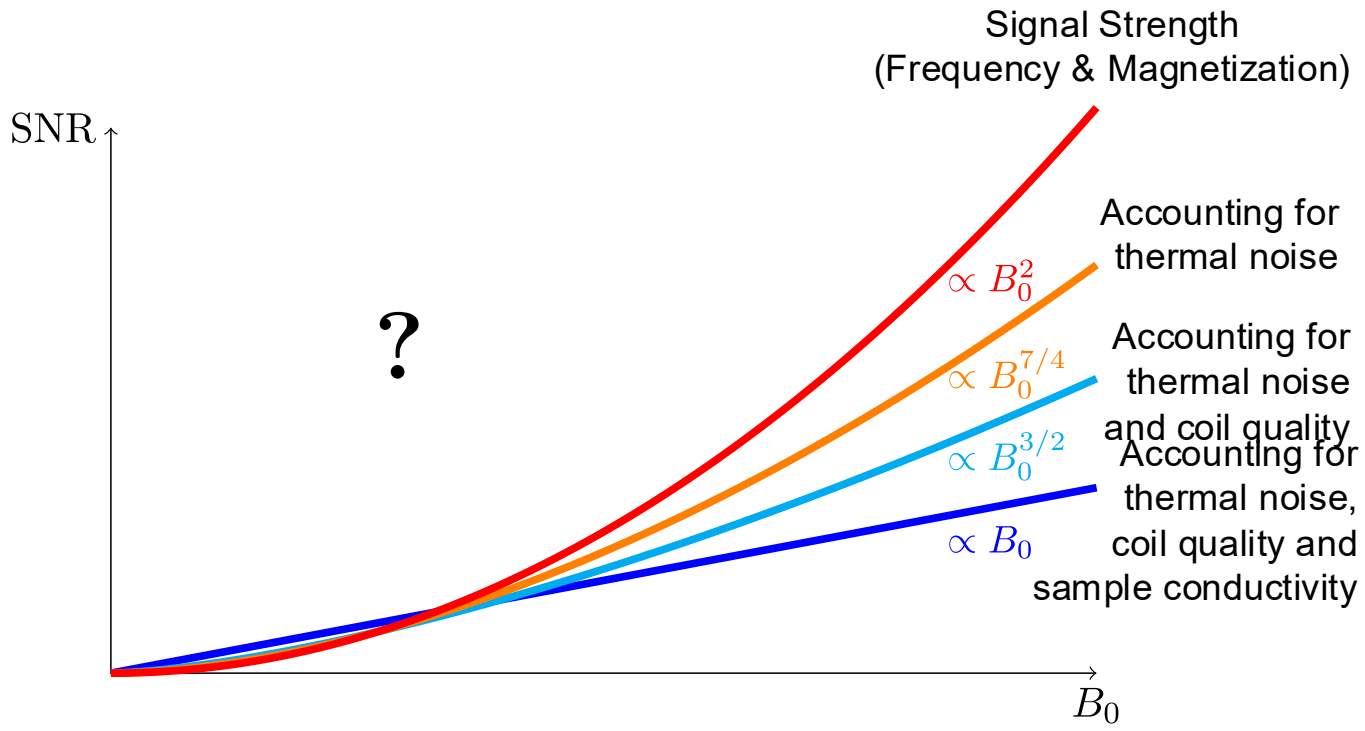
$$\gamma \times B_0 = 42.57 \text{ MHz/T} \times 7 \text{ T} = 297.99 \text{ MHz}$$

Close enough… 😋

Why Do People Use 7T?

- So we go to higher field strengths (B0), but why?
- The simple explanation is:

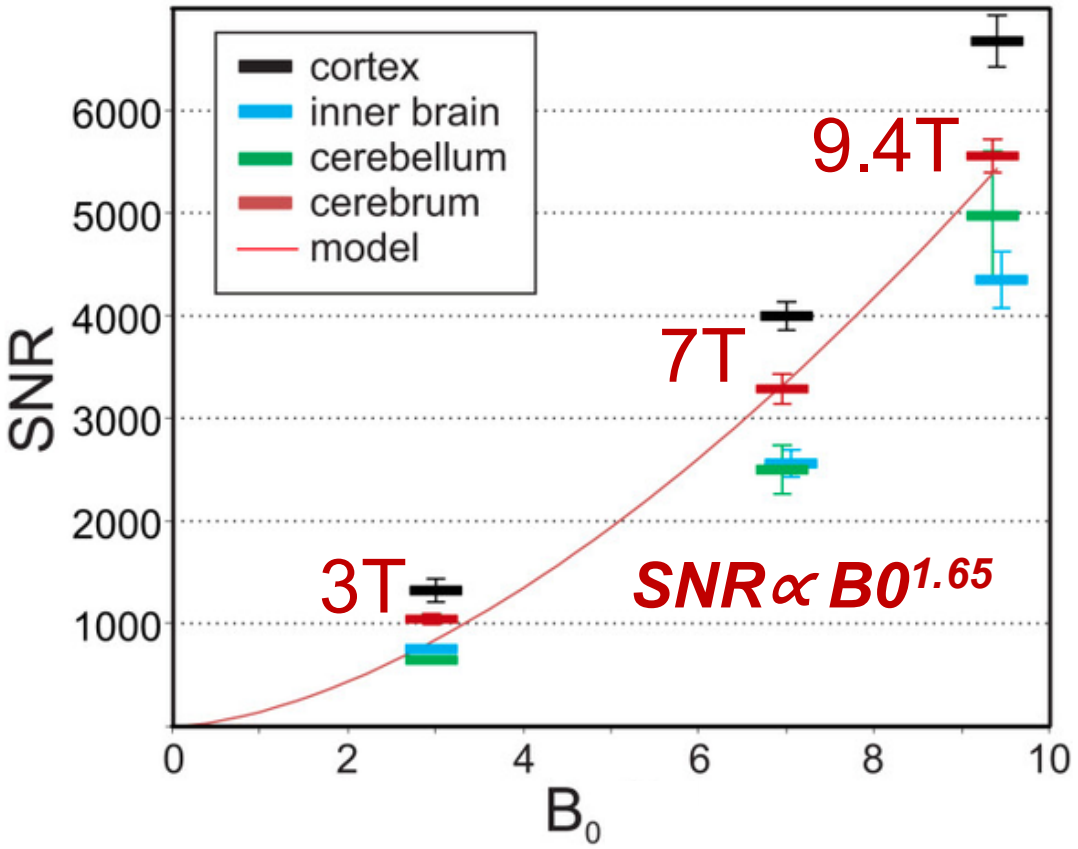
  Signal increases with field strength!



Olaf Dietrich blog *(https://dtrx.de/od/mmm/mmm_20180222.html)*

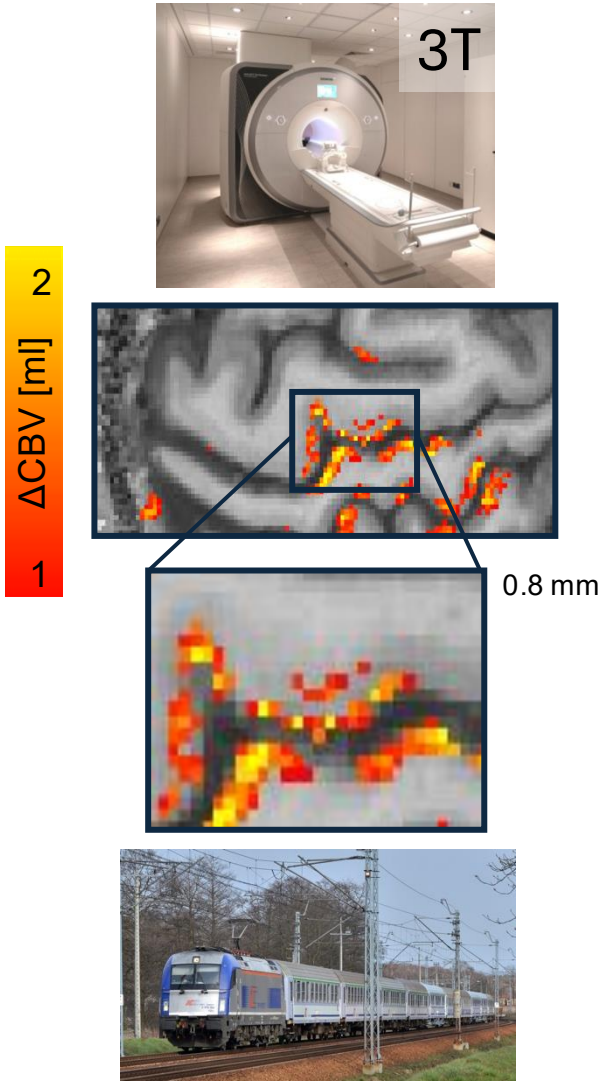
Signal Strength at 7T

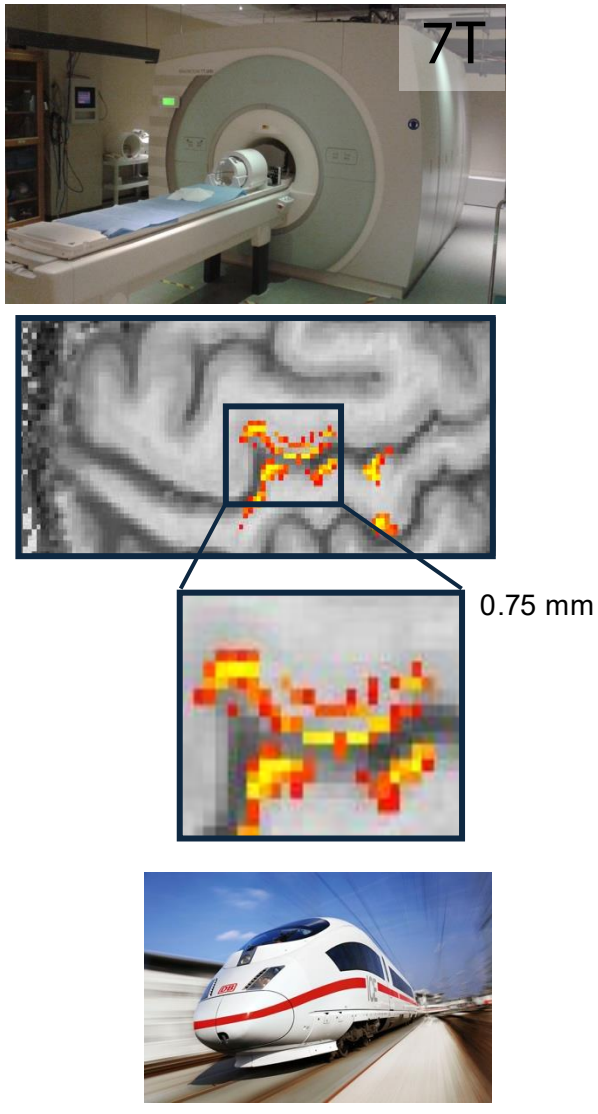
- Empirical data seem to be something in the middle…
- This function makes 7T a good deal!
- We get a big increase in SNR compared to 3T, and we avoid the intense engineering challenges at higher magnetic fields

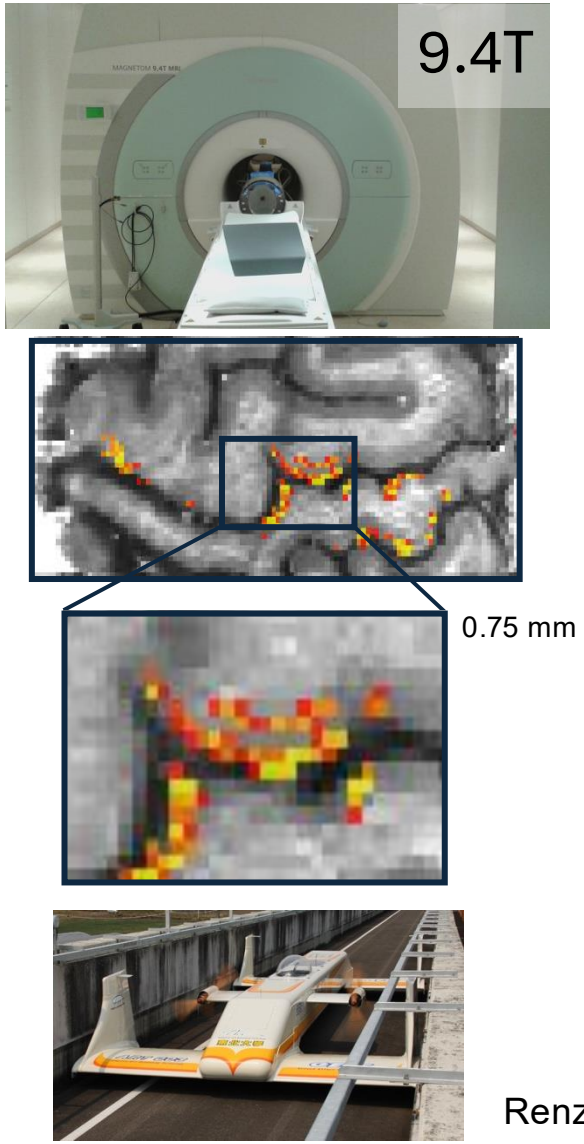


Pohmann, et al. 2015

Field Strength of MRI



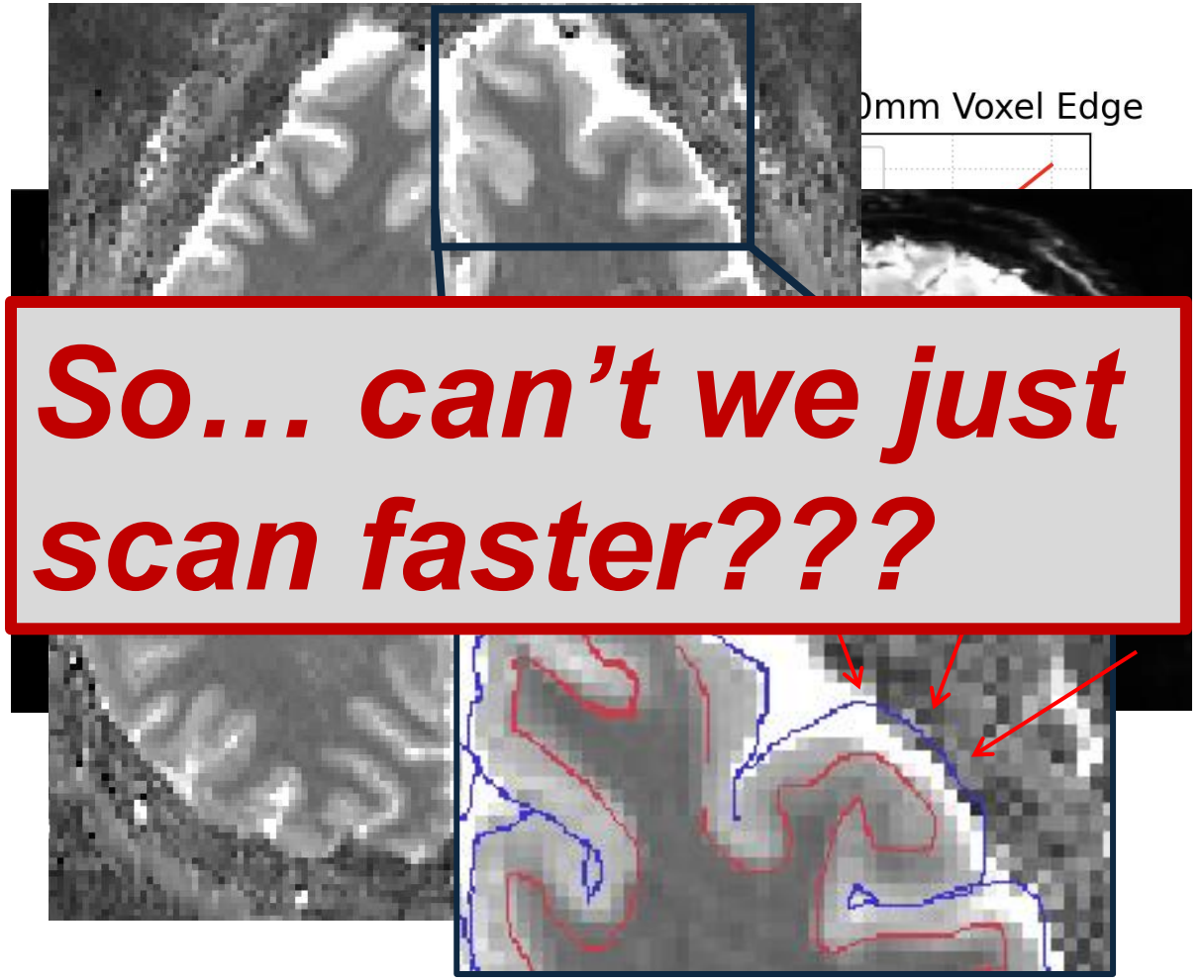




From Renzo Huber

But 7T is not magic…

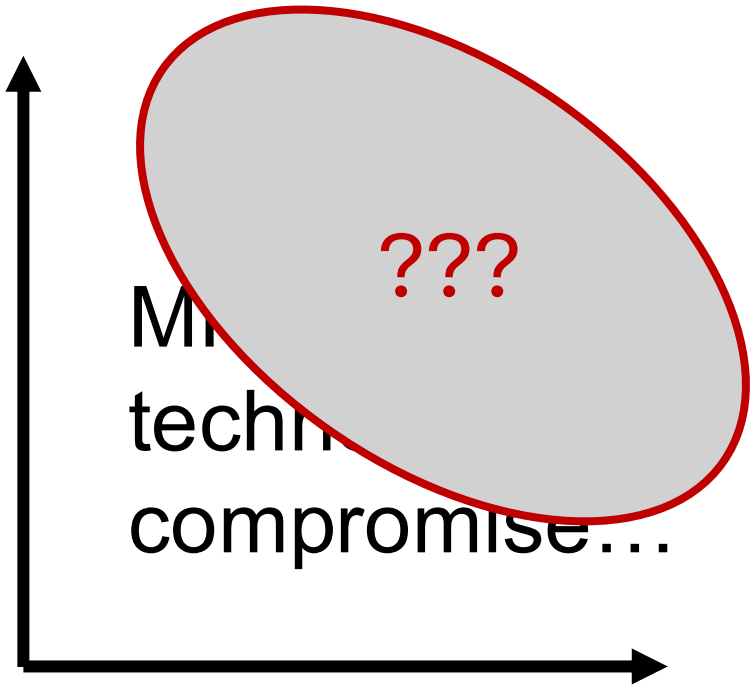
- It comes at a cost!
- Even though signal is higher, we lose it ***faster!!***
- Plus, phase accumulates faster at 7T when reading out the same size voxels when shimming isn't perfect
- Together, these effects mean that if we cannot get through k-space fast, we will have image distortions
- Bad news if we care about small structures like cortical layers!

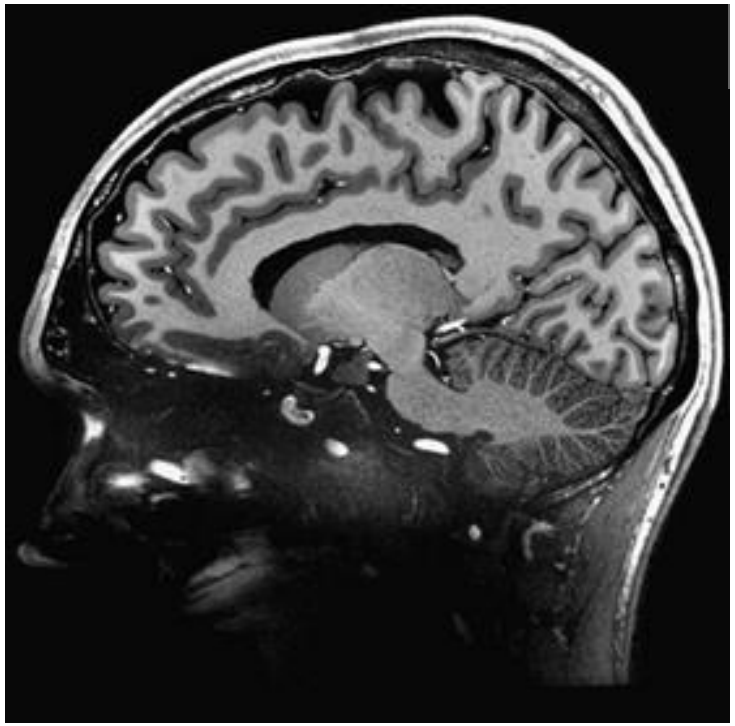


How do we image faster and increase resolution?

Increase
Field Strength

(get same amount signal
in shorter time)





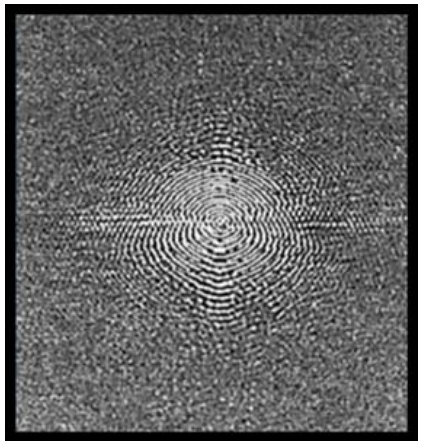
7T

250 um, but **3.5** hours!

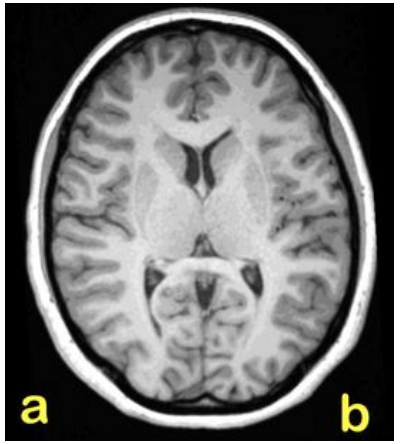
Lüsebrink, et al. 2017

How do we image faster and increase resolution?

We want to record k-space



Fourier Transform ⟷

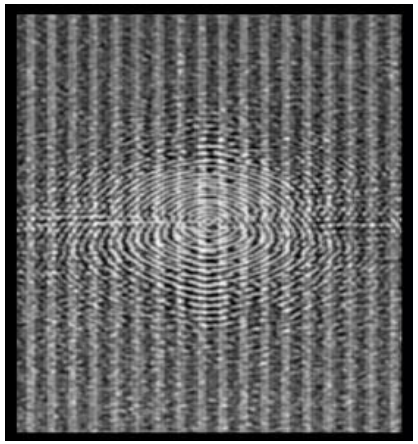


BUT WHAT ABOUT THE SPEED UP????

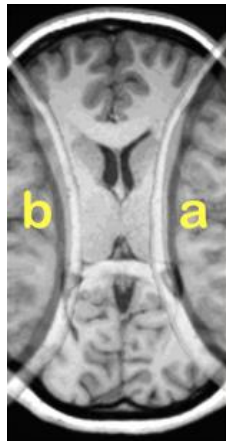
To reconstruct our images

***See Lecture 3 by Vinai*

It would be great to skip lines…

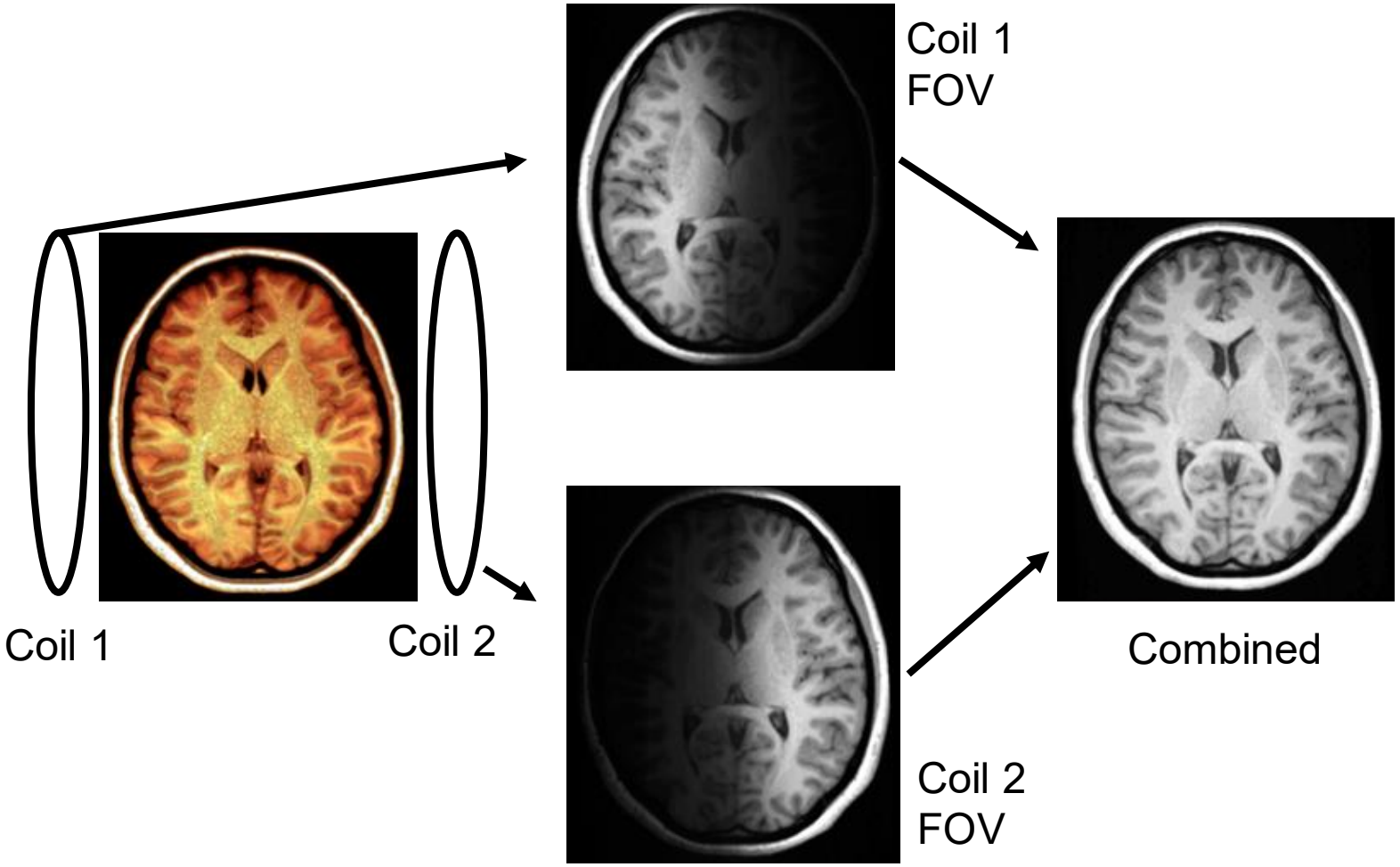


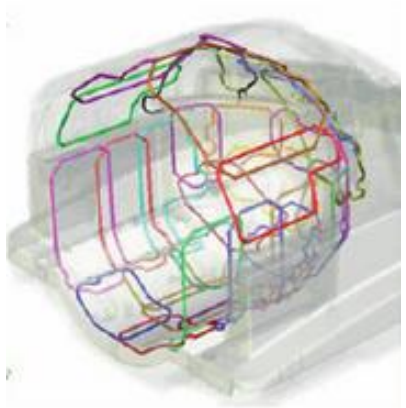
⟷ Fourier Transform



But then we are left with reduced FOV and wrapping artifacts!

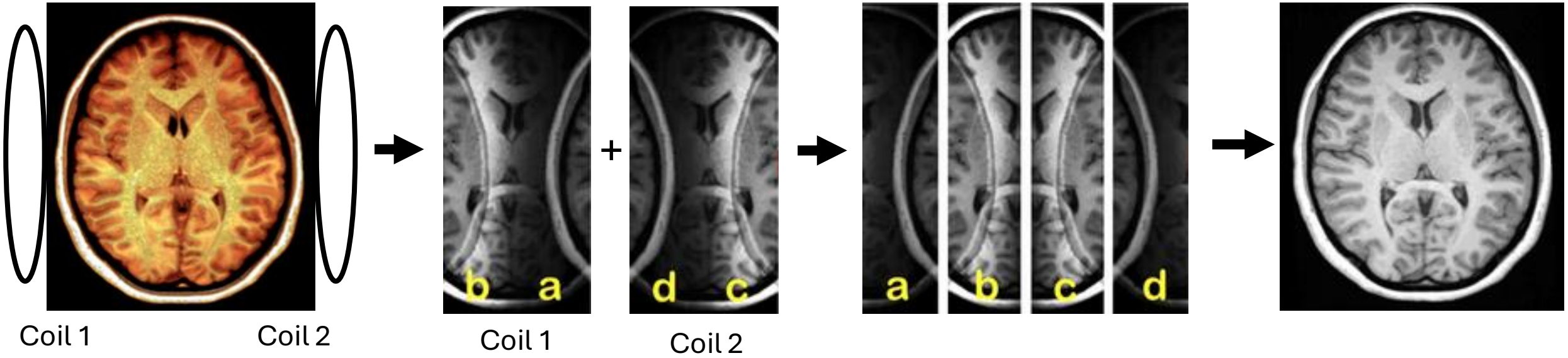
Enter… Parallel Imaging





MRI Questions; Paolini, et al. 2015

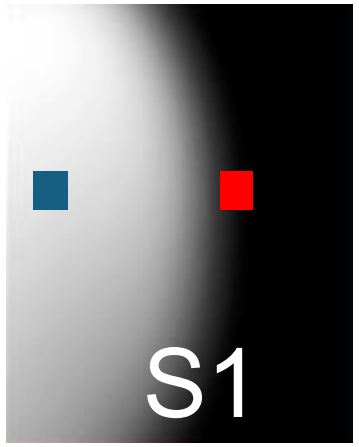
The Acceleration Problem

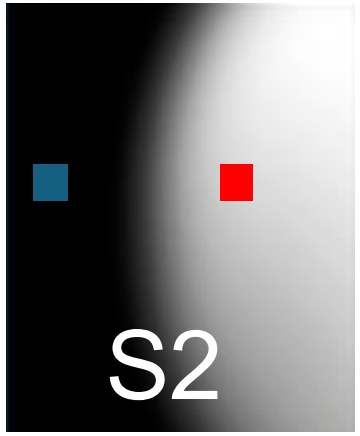


So how do we go from this?

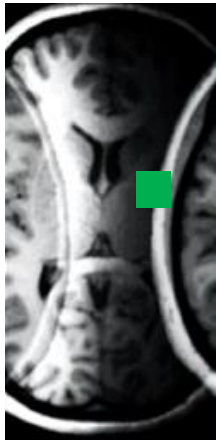
To this???

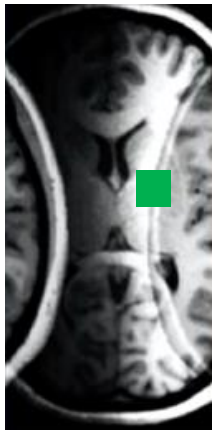
SENSE / ASSET



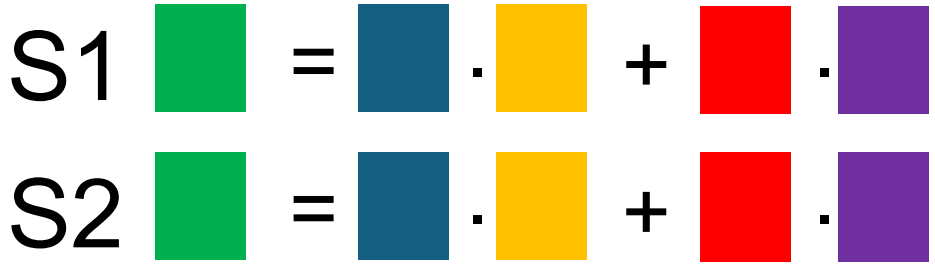


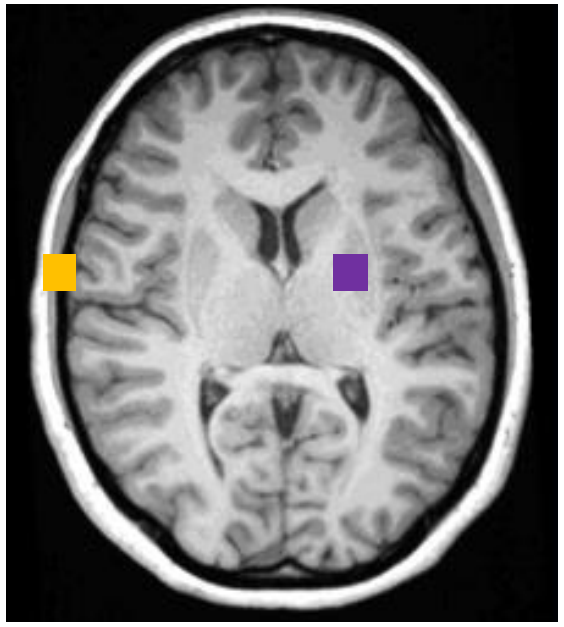
Coil Sensitivity Maps





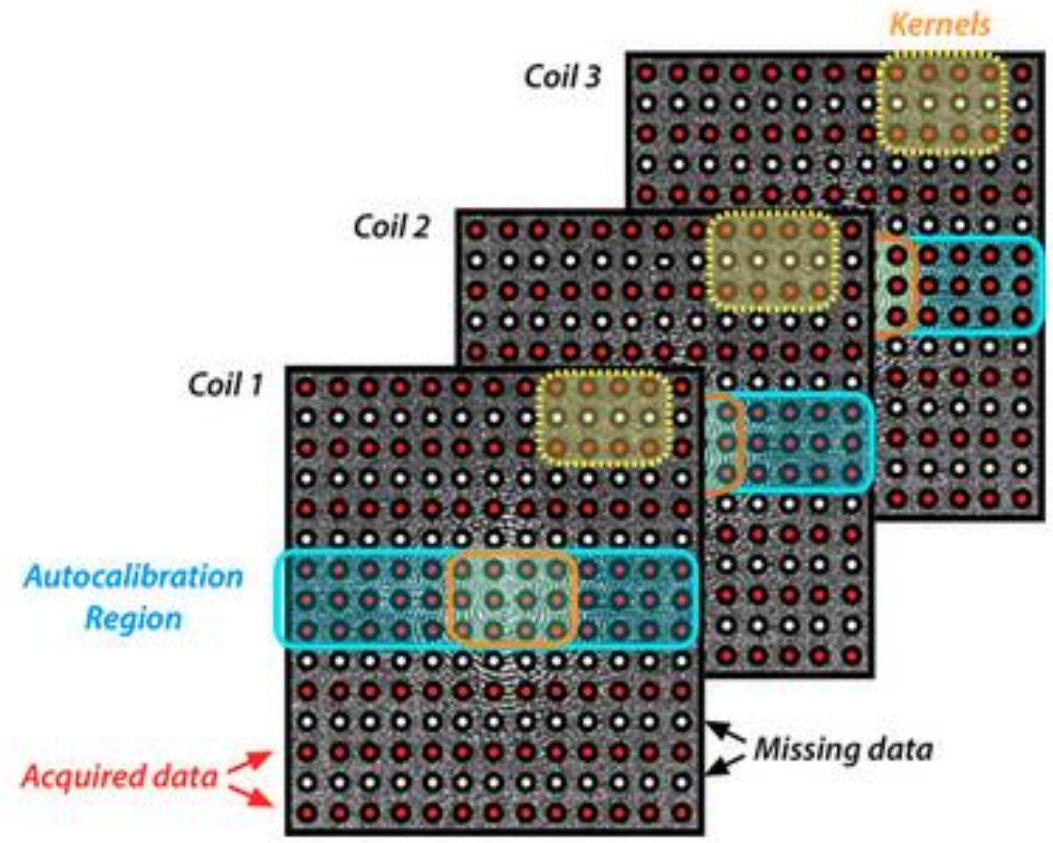
Measured Images

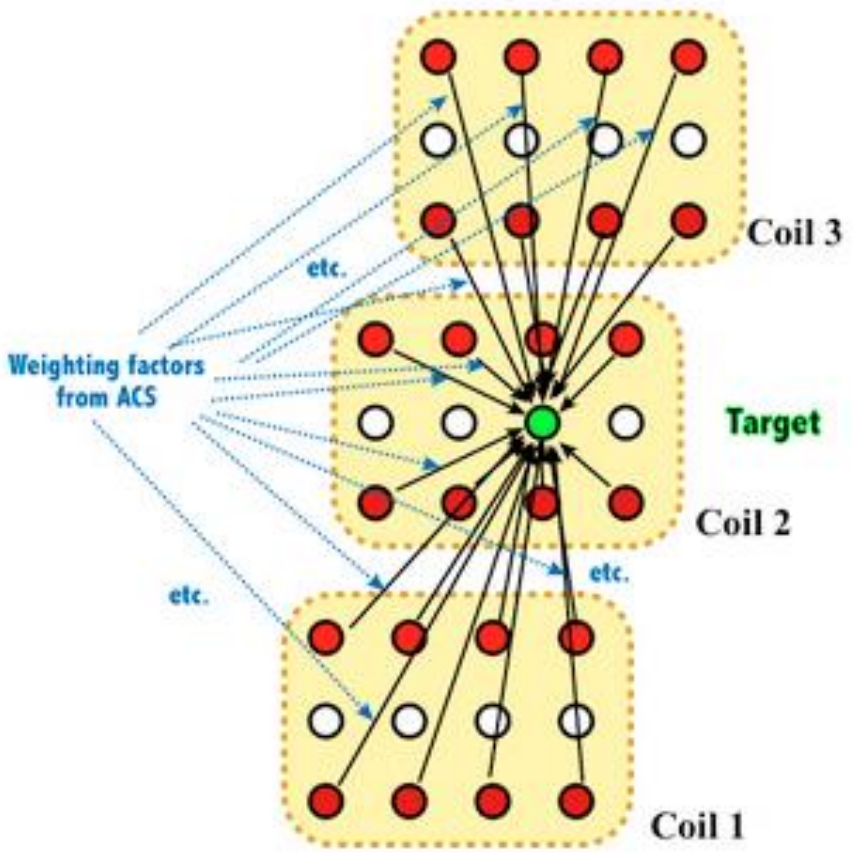




Full FOV Image

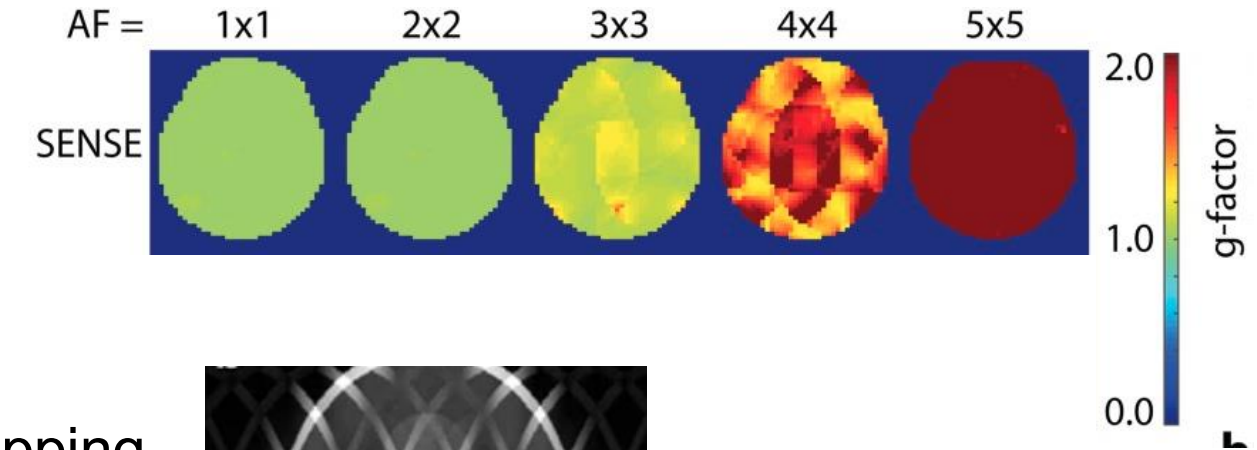
GRAPPA / ARC

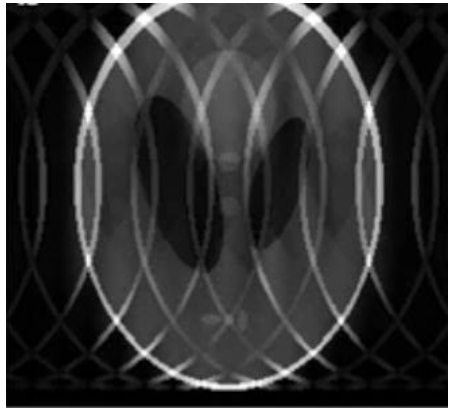

Kernels
Coil 3
Coil 2
Coil 1
Autocalibration Region
Acquired data
Missing data


Coil 3
etc.
Weighting factors from ACS
Target
Coil 2
etc.
etc.
Coil 1

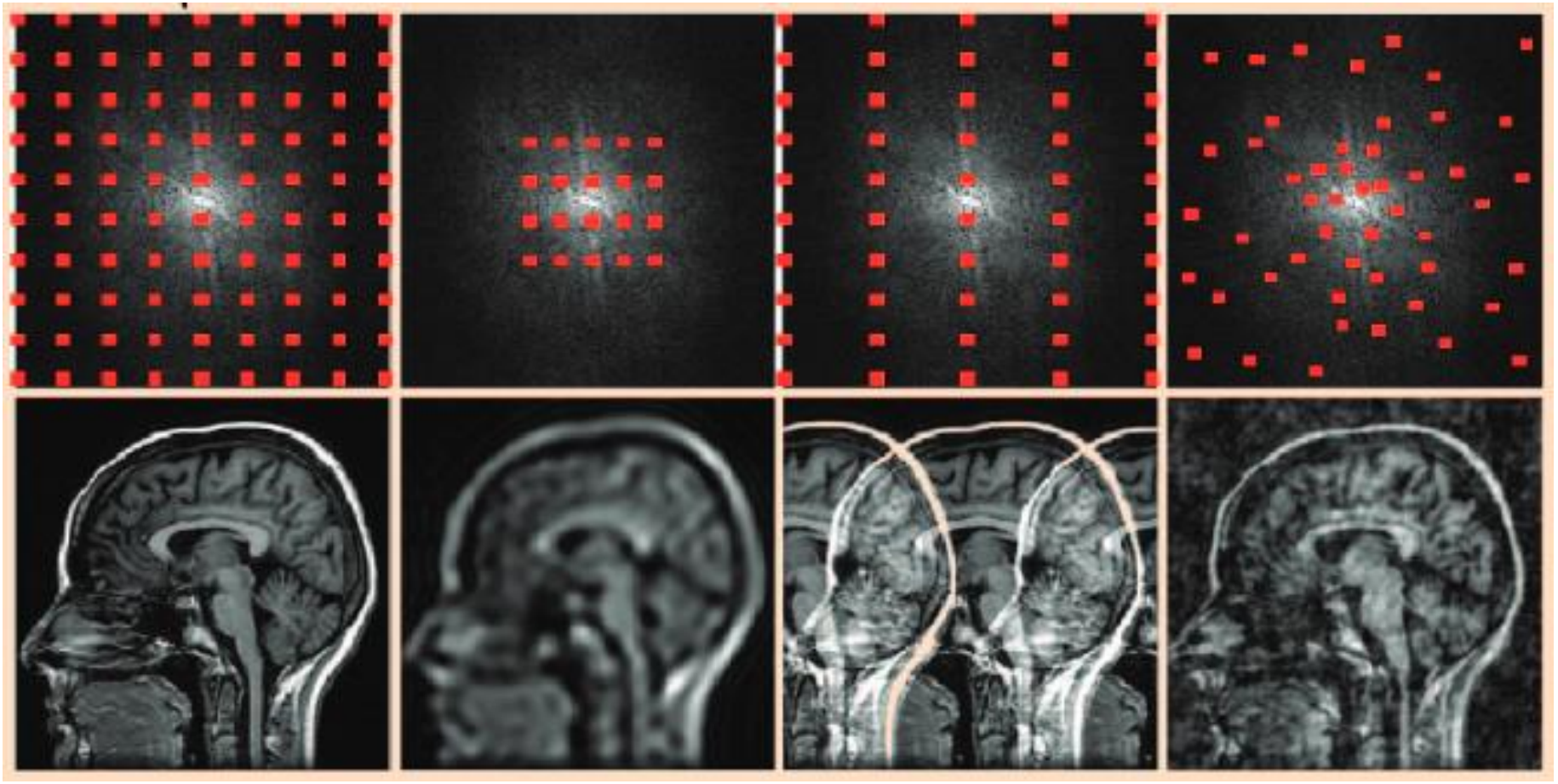
What are the limitations of acceleration?

- All Parallel Imaging techniques are limited by the number of receiver coils, and their arrangement!
- Noise is cumulative! Voxels with similar sensitivity across all coils are harder to untangle (G-Factor penalty).
- Algorithms are never perfect…. some wrapping artifacts will always be present





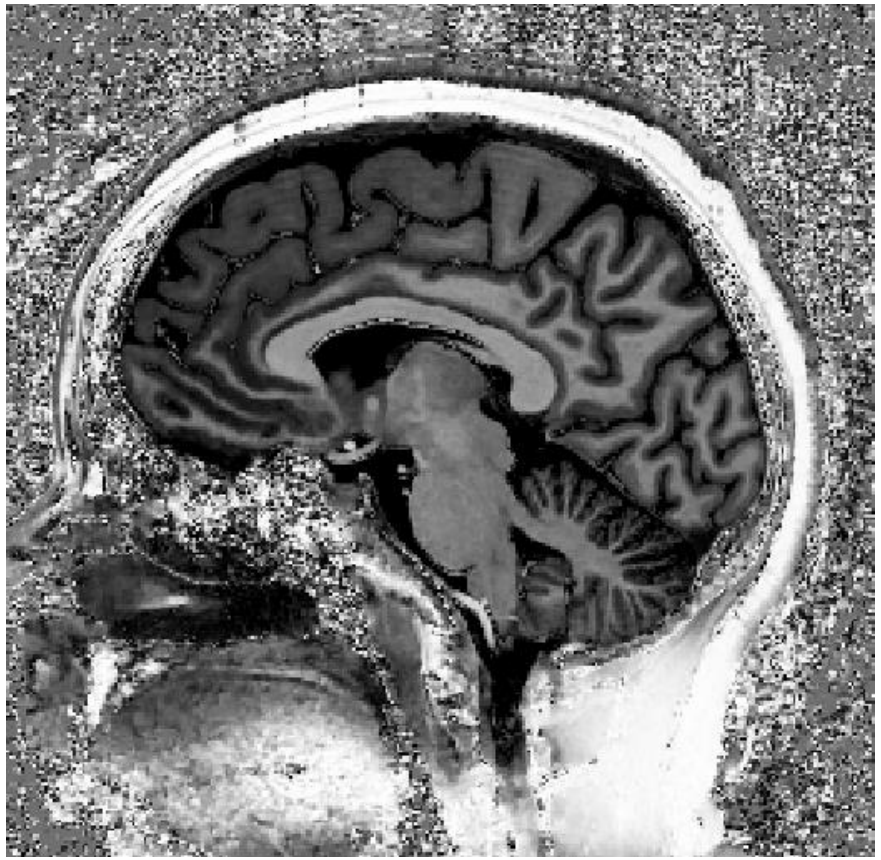
Reducing Artefact Coherence (Compressed Sensing)



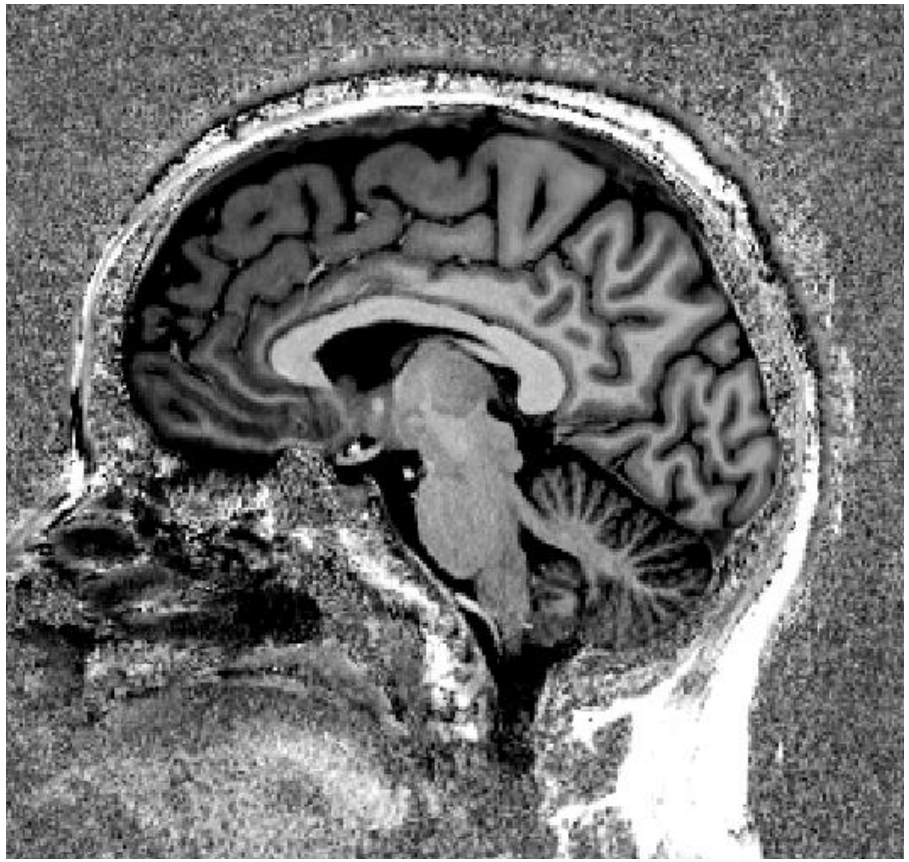
Lustig, et al. 2008

Compressed Sensing (0.75 mm anatomical scans at NIH)

~18% of kspace



CS – USx5.1
(6:04)



~35% of kspace

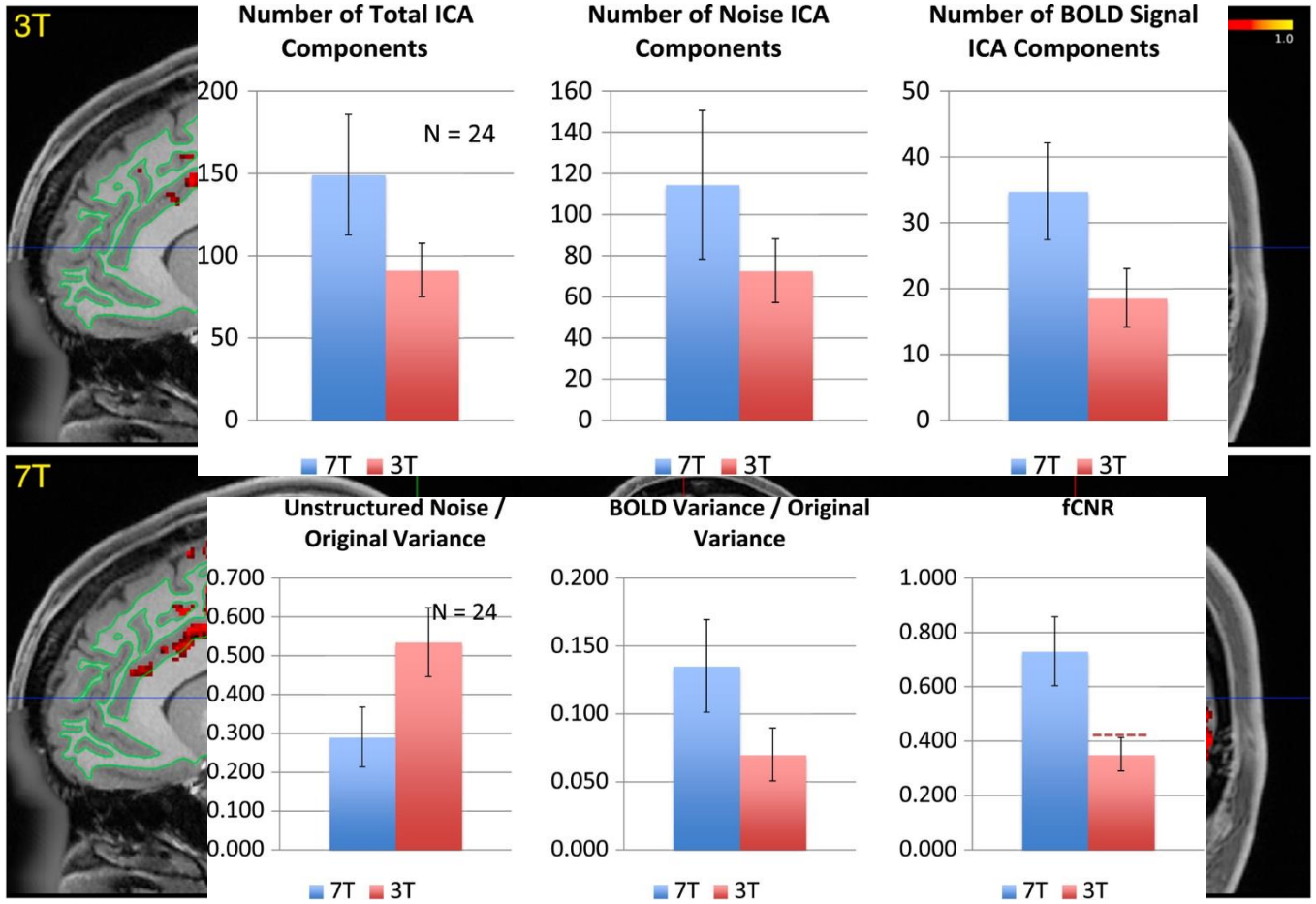
GRAPPA 3
(9:37)

Collected on 7TB

Okay, but is 7T better for fMRI?

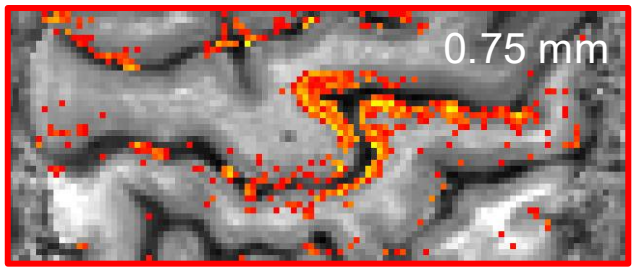
- "*The physics*" show that 7T is better… but is it really better for fMRI?
- Generally, ***yes***.
- 7T provides increased SNR and resolution, which often translates to:

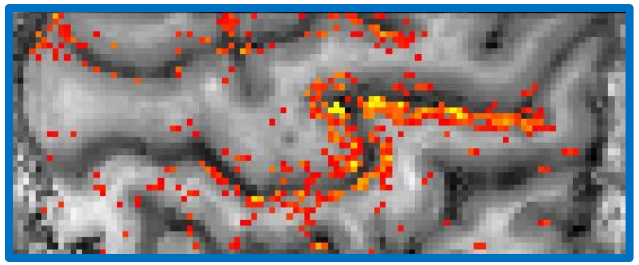
    1. Better functional contrast
    2. More extensive functional components



Vu, et al. 2017 (Human Connectome Project)

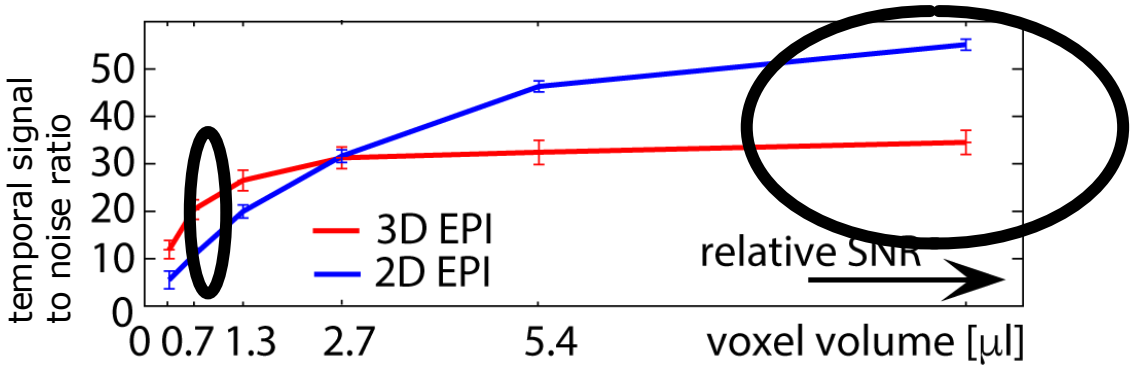
But we need to think about sequences!



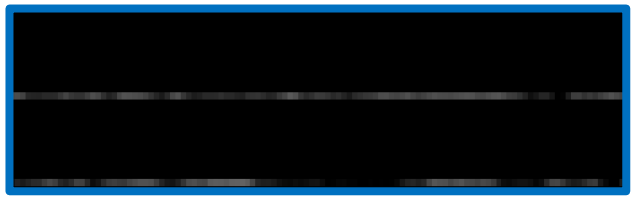


3D EPI

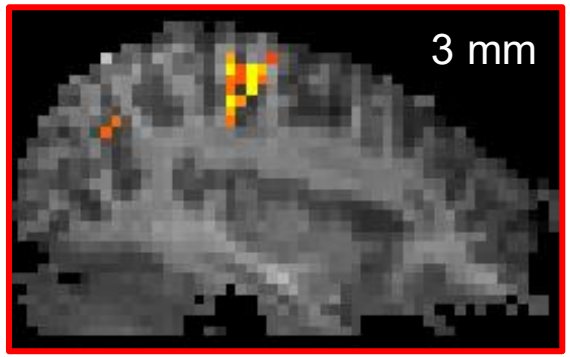
- Higher signal 😍
- but more motion artefacts 😢
- No slice timing
- Confusion between TR and “VAT”

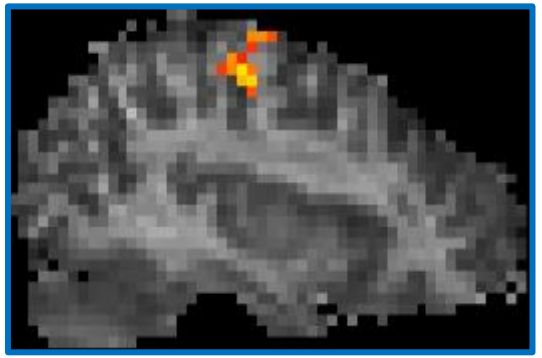


2D MB/SMS



- Lower signal 😢
- but fewer motion artefacts 😍
- Pretty standard processing

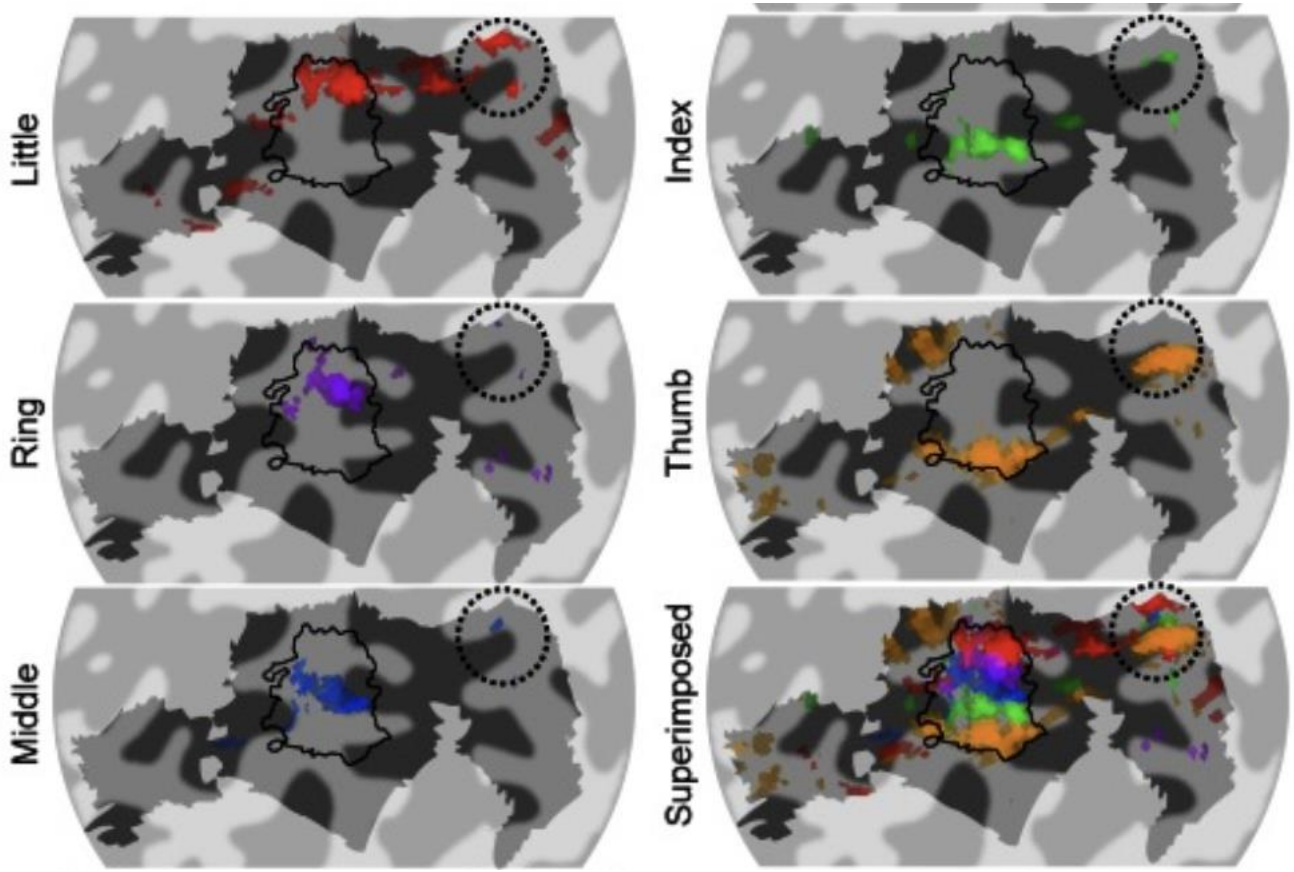




From Renzo Huber

Cortical Columns in fMRI

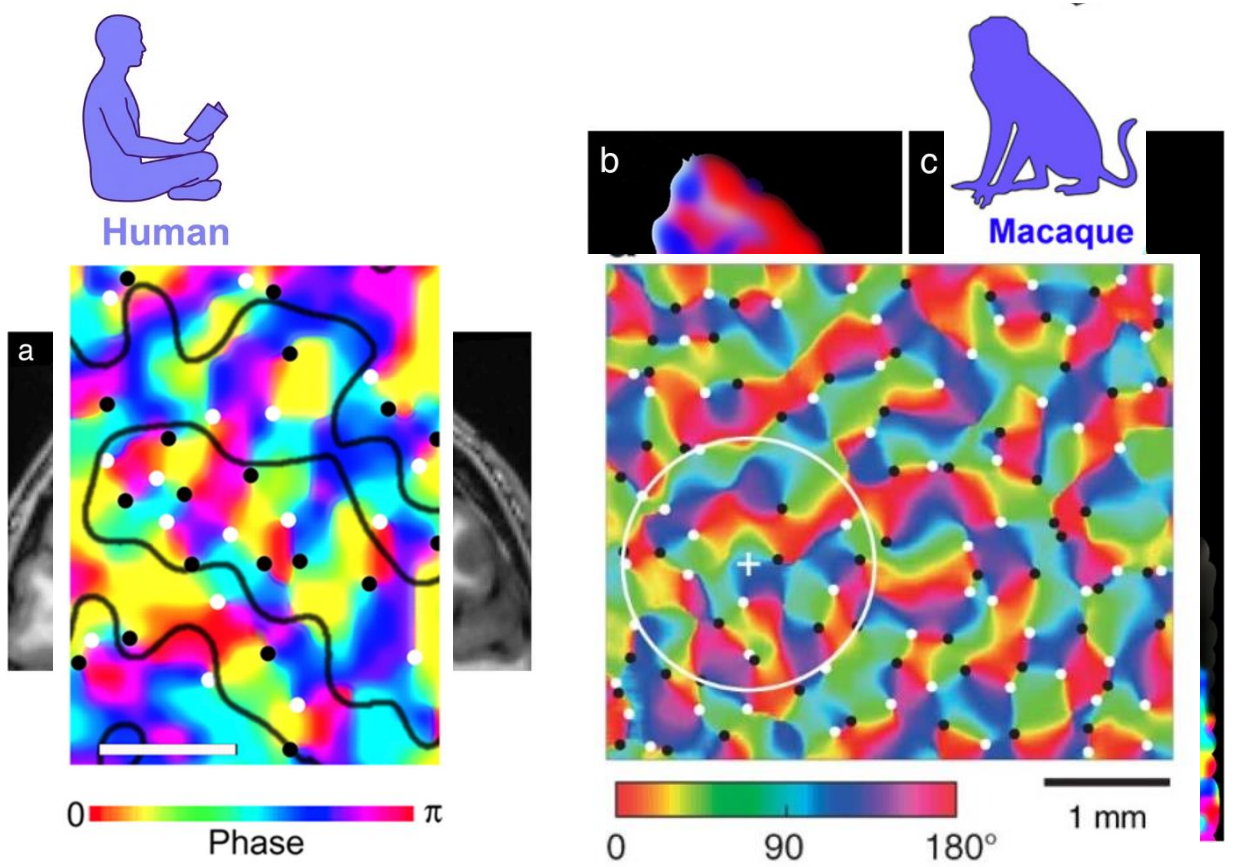
- The specificity of 7T MRI enabled individual finger response mapping in single subjects
- These maps and subsequent experiments have provided valuable information on hand dystonia.



Martuze, et al. 2012; Besle, et al. 2013; Asghar, et al. 2026

Cortical Columns in fMRI

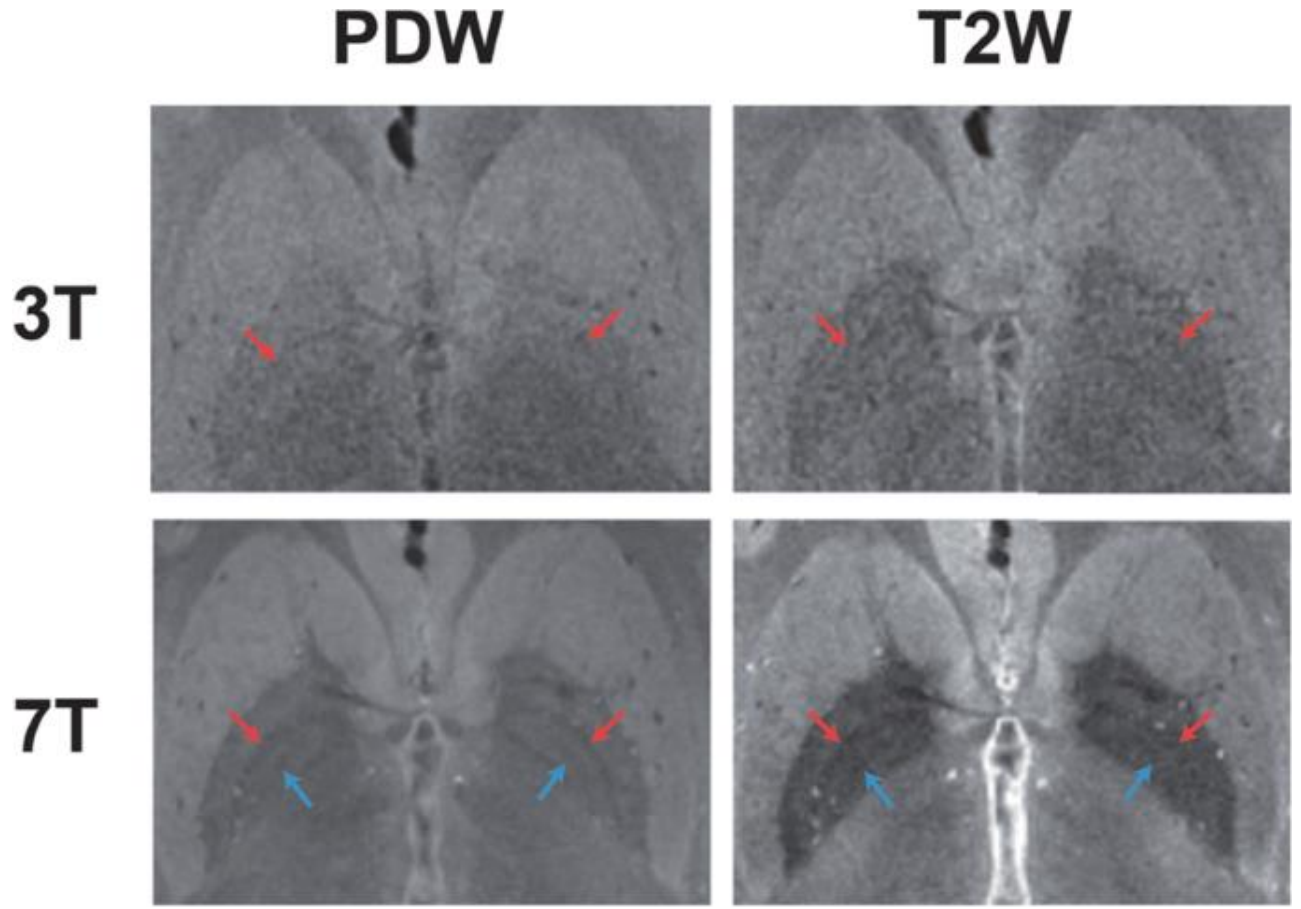
- Yacoub (2008) showed that it was possible to see cortical columns using fMRI
- In a flat portion of cortex, they mapped ocular dominance and orientation selectivity in V1



Yacoub, et al. 2008

Anatomical Mapping of Small Brain Structures

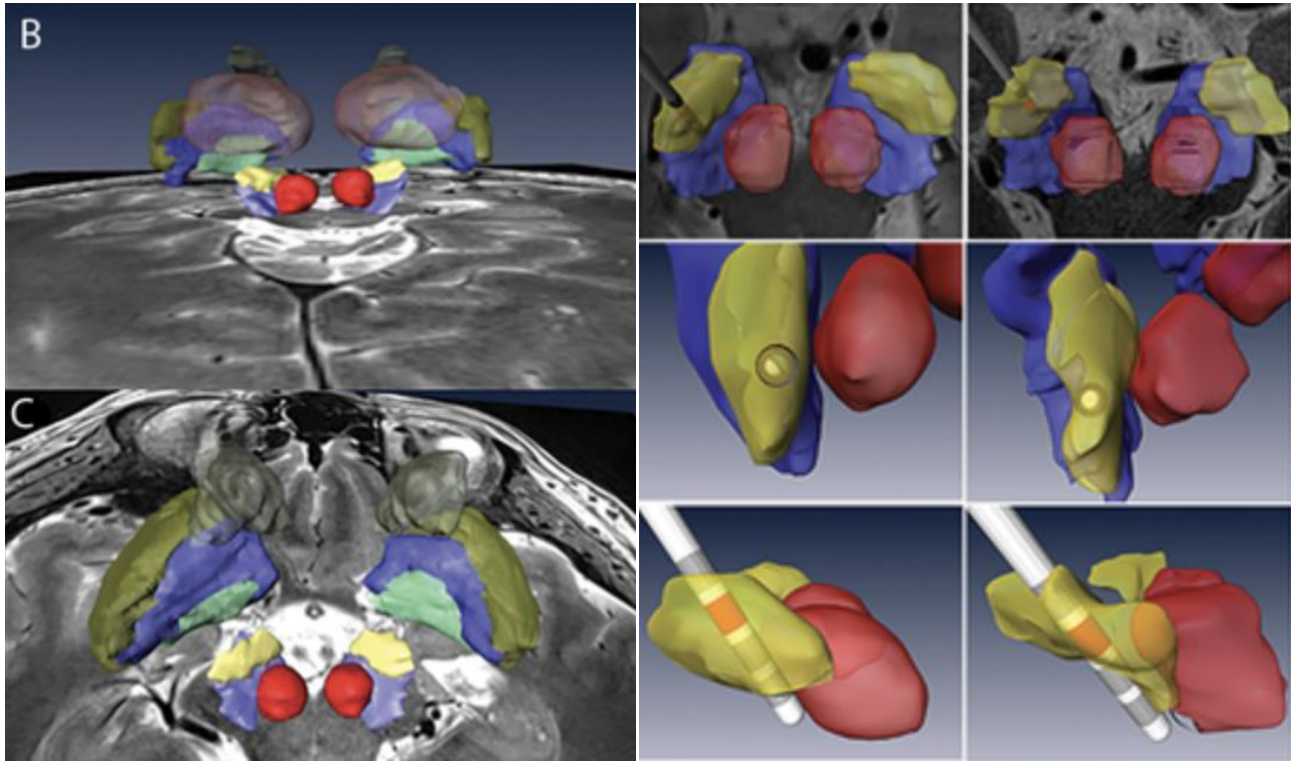
- 7T MRI can be used to create detailed maps of subcortical structures.
- 7T can also deliver unprecedented detail via *ex vivo* brain mapping (100 µm resolution)



Maruyama, et al. 2019; Edlow, et al. 2019

Clinical Use of 7T MRI

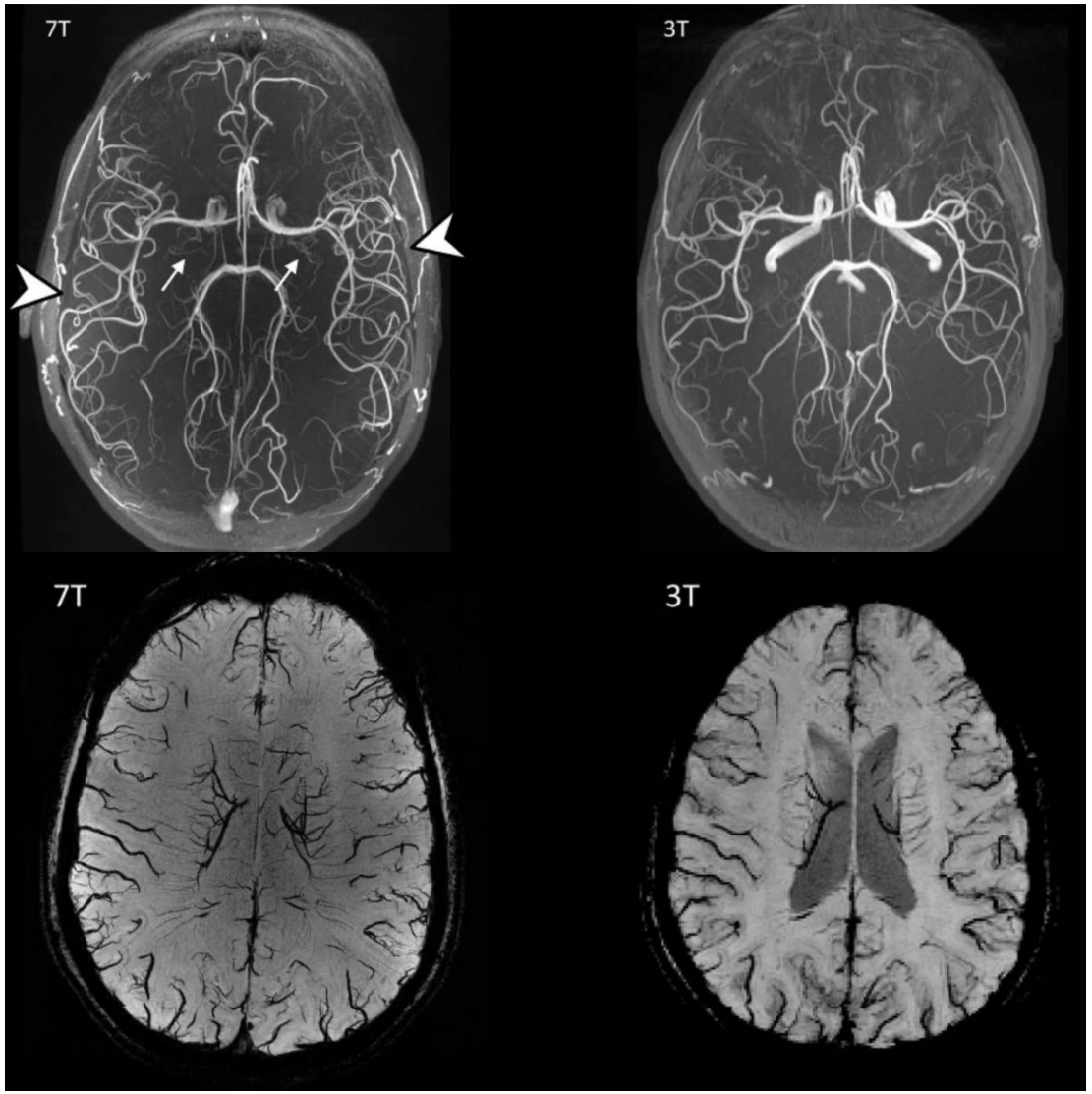
- 7T MRI is used in cases where high resolution is important for accurate diagnosis and treatment
- One example is surgical planning and confirmation of deep brain stimulation. This requires accurate differentiation of subthalamic nuclei from the substantia nigra.



Barisano, et al. 2018

Clinical Use of 7T MRI

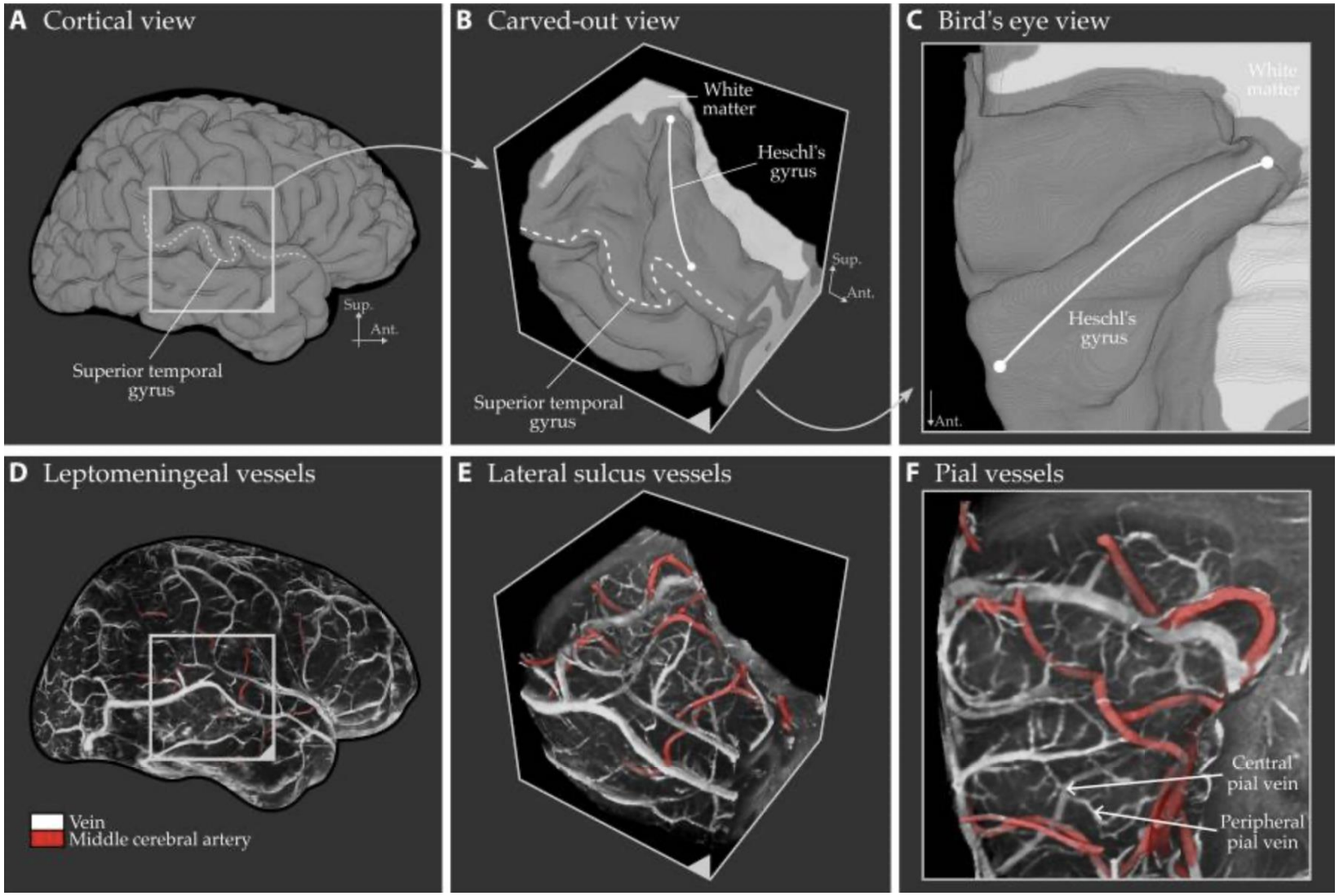
- 7T MRI is used in cases where high resolution is important for accurate diagnosis and treatment
- Other examples include stroke and small vessel disease, where the increased detail provided by 7T MRI can be very informative



Barisano, et al. 2018

Mesovein protocols

- Vascular protocols can also be used for neuroscientific questions
- Increasingly detail maps of arteries and veins is helping us better interpret fMRI signals by examining their sources



Gulban, et al. 2026

Mesovein protocols

- Vascular protocols can also be used for neuroscientific questions
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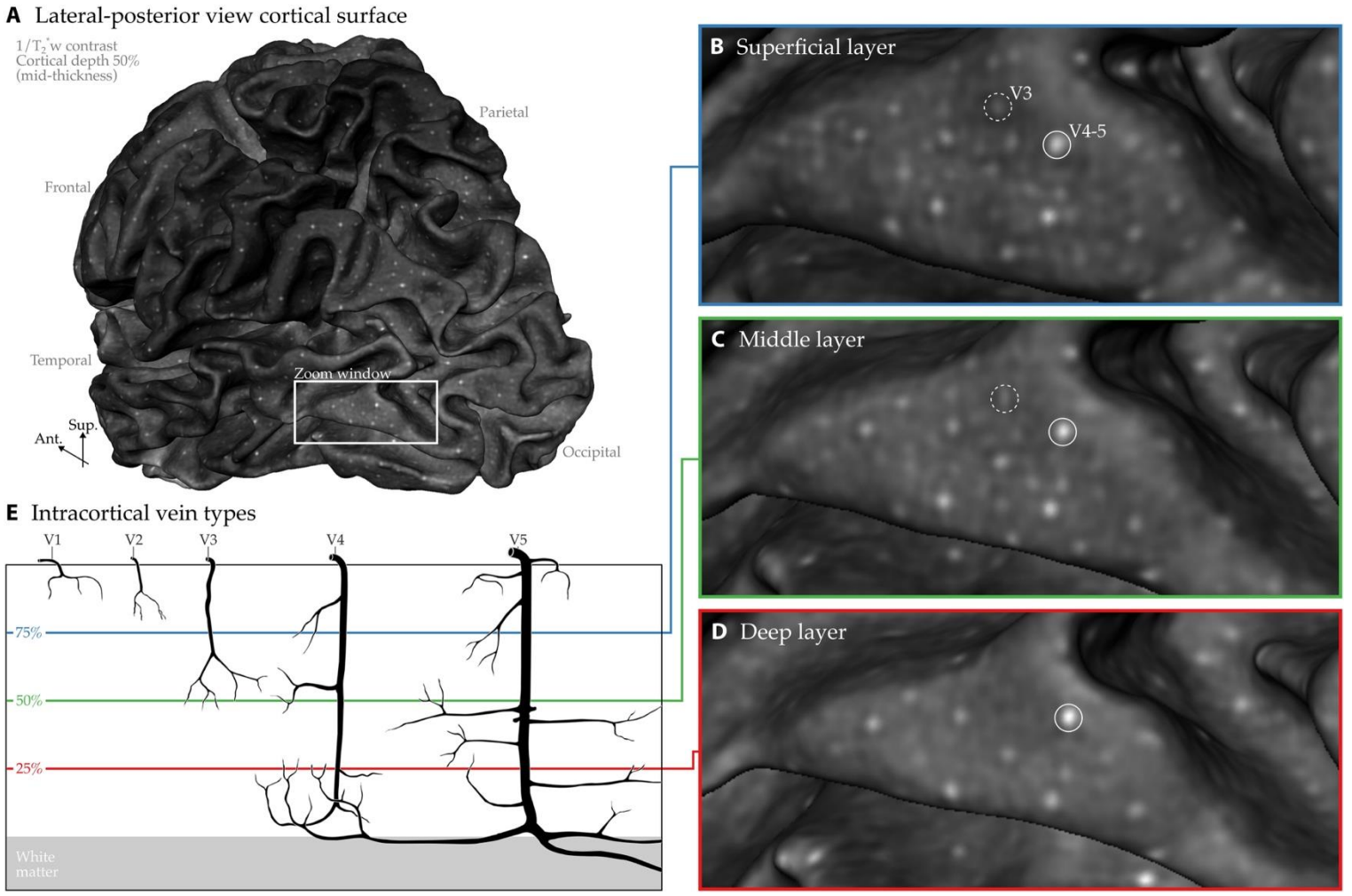
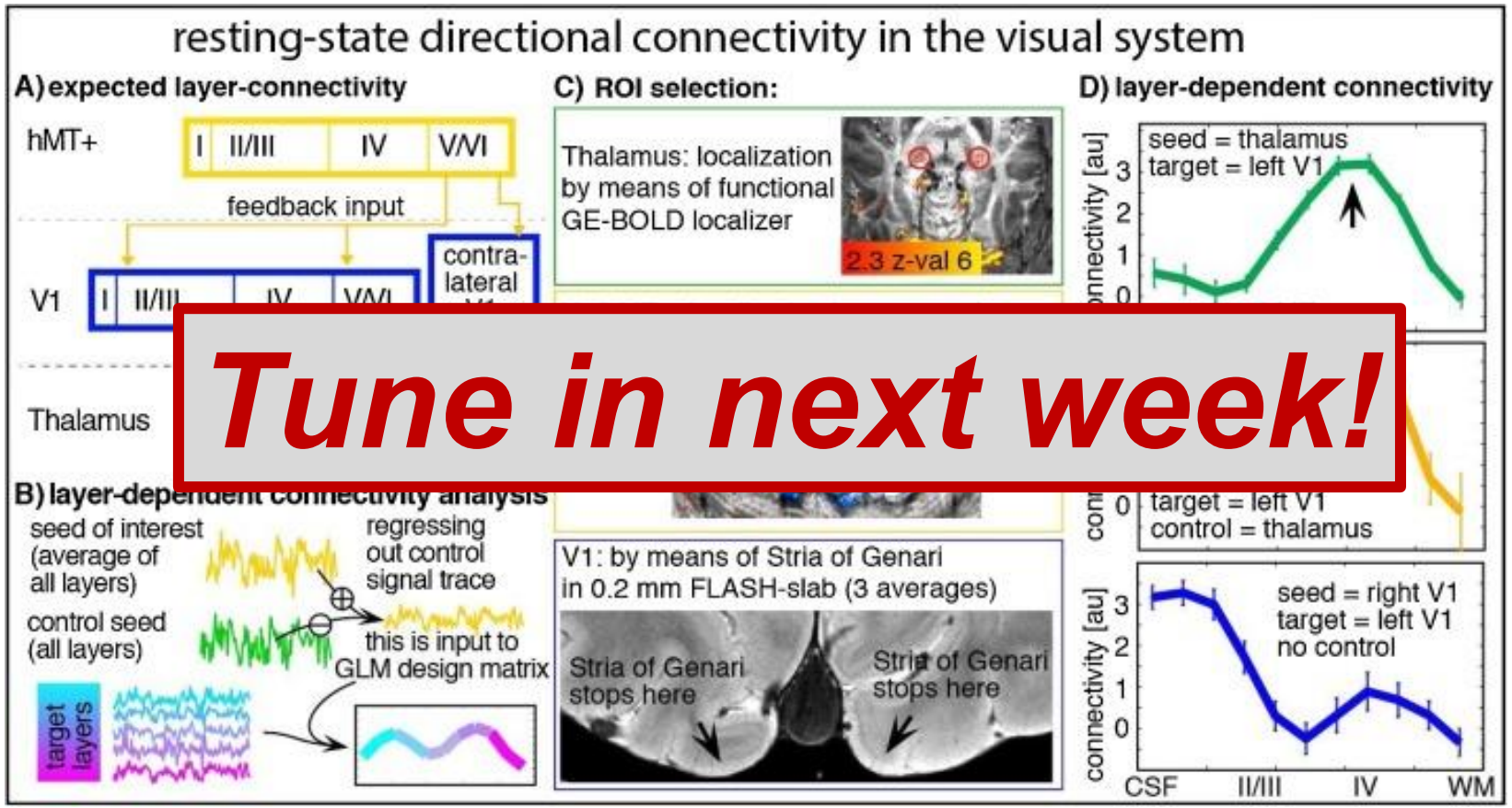


Gulban, et al. 2026

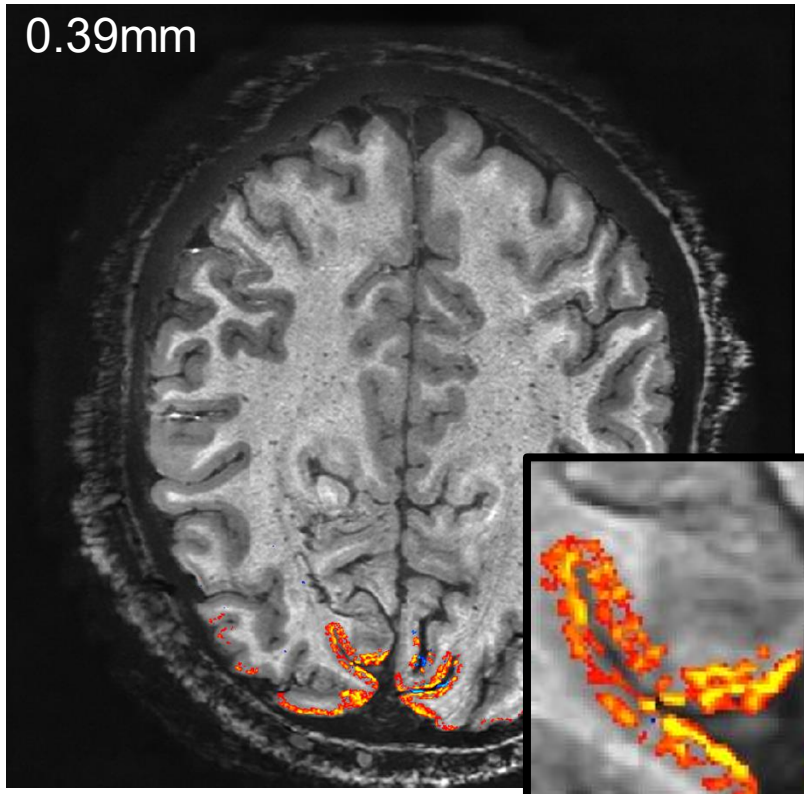
The Promise of Layer fMRI

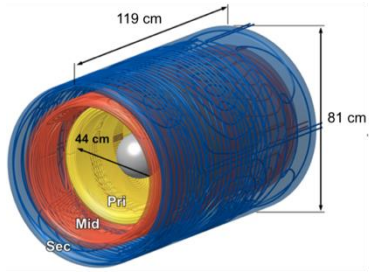
- There is a lot of excitement surrounding the field of Layer fMRI.
- One of the most promising areas is the idea that layer-specific connectivity patterns may provide clues to the direction of information flow in the human brain…

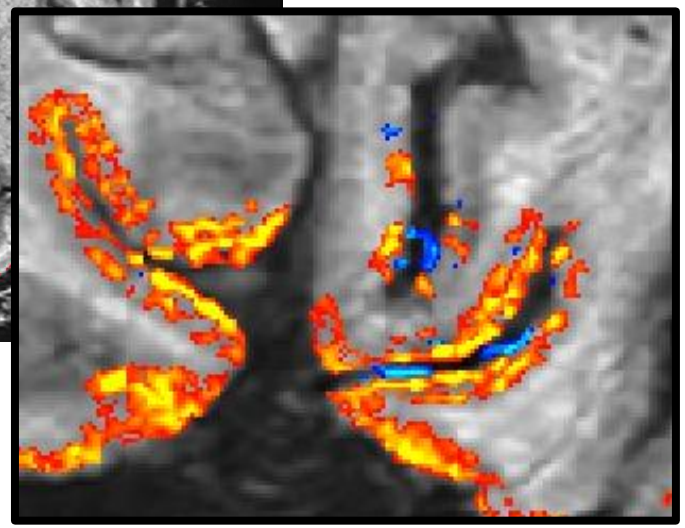


Huber, et al. 2021

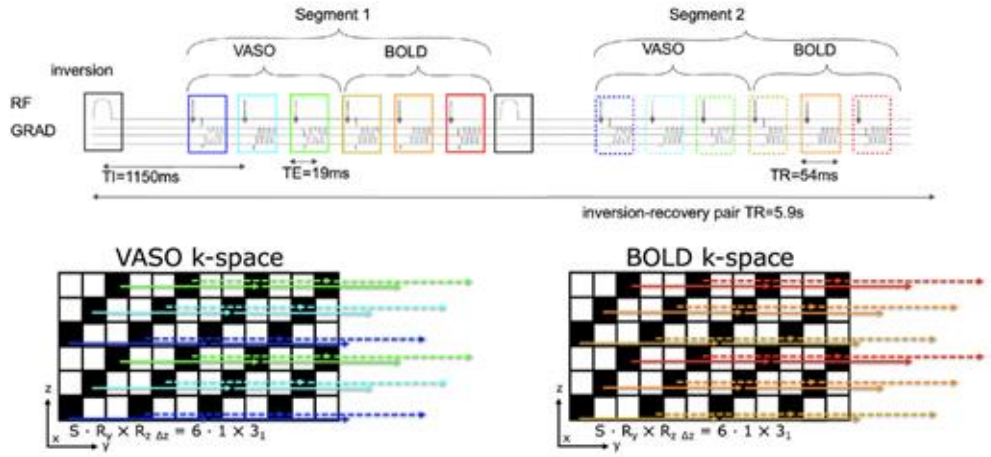
Future Steps to Improve 7T fMRI



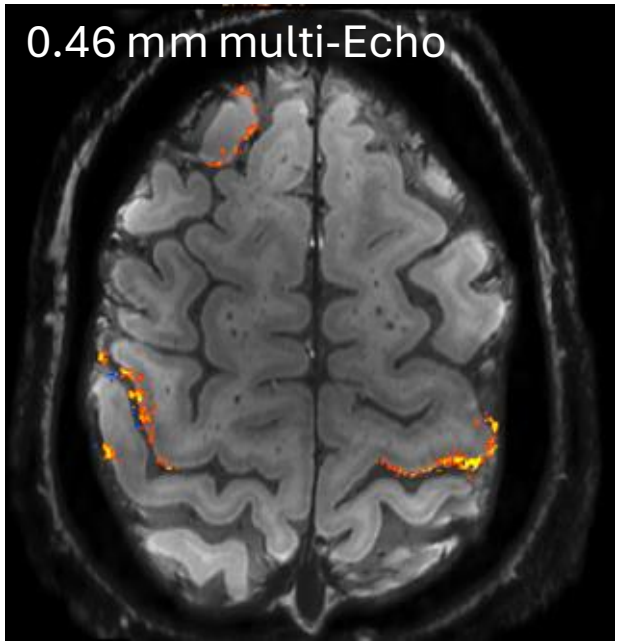


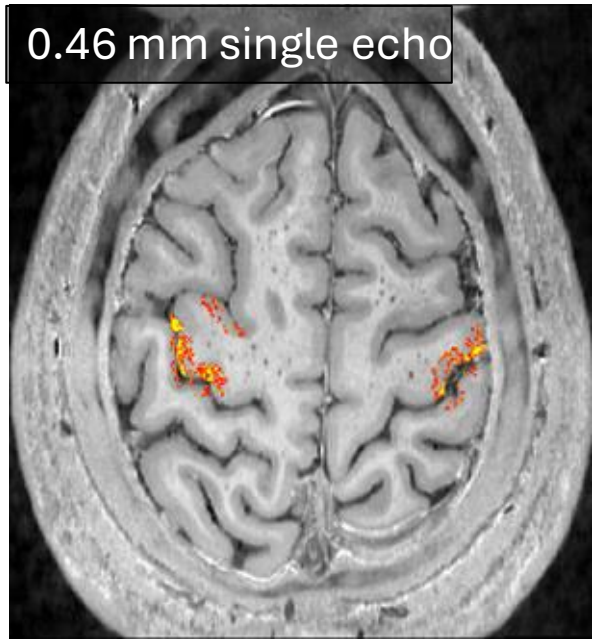


NexGen 7T
UC Berkley



7TB





Feinberg, et al. 2023; Huber, et al. 2026

High Resolution fMRI Educational Resources

- ISMRM Conference
- ISMRM Brain Function & High Field Study Groups
- Layer fMRI Journal Club (https://layerfmri.com/seminar/)
- Layer fMRI Dinners (https://layerfmri.com/dinners/)